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Water-Ratio Specification for Concrete and Its Limitations

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HIGH POINTS IN THE PAPER

The water-ratio specification as used in the construction of the Portland Cement Association building in Chicago involves the specification of concrete proportions not in terms of cement, sand, and coarse aggregates but primarily in terms of gallons of water per bag of cement. Water-ratio means ratio of volume of water to volume of cement in the mix.

The relation of fine to coarse aggregate within certain limitations is entirely under the control of the contractor.

The consistency of the concrete is stated in terms of the slump test.

The basis for the water-ratio specification is the compressive strength, water-ratio curve established as an average of the thousands of test results obtained at the Lewis Institute, Chicago.

The following comments are offered on certain features of the water-ratio specification.

The water-ratio strength relation upon which the water-ratio specification is based is an average relation only. It is disturbed if there is a change in the strength of cement, grading, strength, surface characteristics and shape of either fine or coarse aggregate, different combinations of fine and coarse aggregates, temperature of concrete during the curing period, character of curing and perhaps other conditions. The effect of some of the above factors very seriously changes the water-ratio relation.

The water-ratio relation is therefore not a single relation but a series of relations, each relation applying to a particular set of conditions. This is equivalent to saying, that a constant water-ratio does not insure constant strength unless all other conditions are constant, such as aggregates, curing conditions, temperature, etc. When different aggregates are used the same strength may be obtained with different water-ratios.

The safe way to compare aggregates is by means of preliminary strength tests on concrete made of those aggregates.

The safe way to use a water-ratio specification is to establish by means of strength tests on concrete, the particular water-ratio which applies to the materials being used.

The temperature of curing is a source of serious error not recognized in the water-ratio specification. A means is suggested whereby this error may be corrected.

A specification is included, suggesting a modification of the water-ratio specification and embodying the following points:

1. Preliminary strength tests on the materials proposed for use to establish their relative economy and the water-ratio applicable to them.
2. A correction to the water-ratio depending upon the anticipated curing temperatures.
3. The flow table is suggested instead of the slump test for determining the consistency of concrete.

Other suggestions are made with the idea of making this specification one which will produce more uniform and more economical concrete than the water-ratio specification as now written.

As the result of investigations conducted, for the most part by the Portland Cement Association, there has been evolved within the past few years a new type of specification for concrete known as the "water-ratio" specification. Heretofore, it has been the practice to specify concrete proportions in an arbitrary manner, the idea being that when definite amounts of cement, fine and coarse aggregate were used, concrete of approximately the right qualities for the work in hand would result.

In the light of recent investigations, however, it appears that the old type of specification was defective in at least one respect, namely, that it failed to specify the quantity of water to be used in the mixture. Apparently, the water content in a concrete mix is just as important in controlling the strength of concrete as the quantity of cement and the water-ratio specification is aimed at producing concrete more nearly of the strength desired by definitely specifying the maximum amount of mixing water. The specification used for the construction of the new office building of the Portland Cement Association in Chicago is typical of the water-ratio specification and it is quoted in full herewith.

Specification for Concrete and Concrete Material as Used in the Construction of the Portland Cement Association Building, Grand Avenue and Dearborn Street, Chicago[1]

Suggestions to Bidders

Attention to bidders is particularly called to the following concrete specification which differs materially from the ordinary form in that proportions of aggregates are not specified, while a limiting volume of water per sack of cement is definitely fixed.

This form of specification has been adopted because it has been definitely shown by ample tests and construction experience that it is the proportion of water to cement that determines the strength of the concrete. This means that so long as the ratio of water to cement remains the same, changing the amount or grading of aggregate does not affect the strength, but only the consistency or workability of the concrete; provided only that all mixes are plastic and workable and the aggregates clean and structurally sound.

Under this form of specification the contractor is permitted, within certain limits, to use such aggregates and proportions as in his judgment will produce proper economy and workability. By keeping the water-cement ratio constant, uniform strength is assured, while the necessary consistency is obtained by varying the aggregate proportions as desired. Increasing the quantity of aggregate for each unit of volume of cement, with its fixed ratio of water, increases the yield of concrete, but stiffens the mass and may increase the cost of placing. Increased plasticity can be obtained by reducing the amount of aggregates used with each sack of cement, or by changing the proportions of fine to coarse.

Bidders may find that in order to obtain the consistencies to which they have been accustomed, more cement will be required per cubic yard than was the case where increased fluidity was obtained by simply adding water. It is, therefore, suggested that trial mixtures be made to determine the cement requirements for the different consistencies which they will use in the various portions of the building. In such trial batches, the moisture contained in the aggregate must be taken into account in securing the water-cement ratio specified.

The following figures indicate how the cement requirement varies with the consistency. For concrete mixed with 6 U. S. gal. of water for each sack of cement, a consistency represented by a 6-in. slump would require 1¼ bbl. of cement per cu. yd. and by a 9-in. slump would require about 2¼ bbl. For concrete mixed with 7½ gal. of water for each sack of cement, consistencies represented by a slump of 4 in. would require about 1⅛ bbl. cement per cu. yd. and by a 7-in. slump about 1⅝ bbl. These figures are for average aggregates available in this market. Some variation will be found with different materials or with different gradings.

Attention is further called to the manner in which allowance must be made for batch-to-batch fluctuations in water content. Instead of specifying the average water-cement ratios desired with a definite tolerance, the maximum permissible values have been given, requiring the contractor to so conduct operations that these shall at no time be exceeded. This will enable the contractor to obtain increased economy as his methods of controlling the water are perfected, for, the smaller the variation, the closer the maximum permissible limits can be approximated by the average water content.

1. American Concrete Institute Proceedings, 1926, pages 141, 142, 154, 155 and 156.

The principal difficulties of controlling the mixtures under this type of specification will arise from variations in moisture content and grading of the aggregate, and from inaccuracies in measurement—principally with the sand. The requirement in the specifications, that the source of aggregate be such that uniformity of grading can be assured during any one day's operations, will largely eliminate some of the difficulty. This requirement will be found decidedly to the contractor's interest and one that in this market should offer no hardship. If methods of measuring aggregates are adopted which will give uniform quantities from batch to batch, not only will other difficulties be eliminated, but the annoyance of moisture variation in the sand will be considerably minimized. For, with uniformity in quantities of materials and grading, the correct moisture content in the concrete can be gaged with considerable accuracy by the workability or consistency as indicated by the slump test or by its appearance.

Determinations of the moisture content in the aggregate from time to time will be necessary in order that the water content will at all times be within the water-cement ratios specified. The frequency with which these determinations will be required and the consequent annoyance of making the requisite changes in the mix will depend entirely upon the care used in controlling the grading and uniformity of measurement and the moisture content in the aggregates.

The measurement of moisture in the aggregate within the limit of accuracy specified (2 lb. water in 100 lb. aggregate) should offer no great difficulty. Either drying and weighing a small sample or by inundation will give results satisfactory for the purpose.

Since this is likely to be a new form of specification to the bidder the owners will have on the job or immediately available at all times a man experienced in work of this character who will be ready to advise and assist the contractor in developing methods of carrying out the specifications and in overcoming any difficulties that may arise.

SPECIFICATION FOR CONCRETE AND CONCRETE MATERIALS

Water-Cement Ratio

Concrete for structural members shall be proportioned to give the necessary workability without exceeding the following ratios of water to cement:

Where concrete of strength of 2,900 lb. per sq. in. is called for—	Where concrete of strength of 2,000 lb. per sq. in. is called for—
6.0 U. S. Gal. of water per sack (94 lb.) of cement.	7.5 U. S. Gal. of water per sack (94 lb.) of cement.

These water-cement ratios are the maximum permissible. The mixes shall be proportioned for somewhat lower ratios so that with the normal fluctuations which may be expected from batch-to-batch these ratios will not be exceeded. Water or moisture contained in the aggregate must be included in computing the water-cement ratios. Water absorbed by the aggregate in a period of 30 minutes may be deducted in computing the water-cement ratio.

The water-cement ratios specified shall not be changed except by the architect. In the event that the architect finds it necessary to change the water-cement ratios from those specified, adjustment, covering amount of cement and aggregates affected, will be made as an extra or a credit under the provisions of the contract.

Measuring Moisture in the Aggregate

Moisture in the aggregate shall be measured by a method, satisfactory to the architect, which will give results within 2 lb. for each 100 lb. of aggregate.

Concrete Proportions and Consistency

The proportions of aggregate to cement for concrete of the water-cement ratios specified shall be such as to produce concrete that can be puddled readily into the corners and angles of the form and around the reinforcement without excessive spading and without undue accumulation of water or laitance on the surface. In no case shall concrete be placed which shows a slump exceeding the following limits:

For Caissons	Max. Slump	4 in.
For Heavy Walls, Slabs and Beams	" "	7 "
For Thin Walls and Columns	" "	9 "

The proportion of fine and coarse aggregates shall be such that the ratio of the coarse to the fine shall not be less than 1 nor more than 2, nor shall the amount of coarse material be such as to produce harshness in placing or honeycombing in the structure. When forms are removed, the surface and corners of the members shall be smooth and sound throughout.

Control of Proportions

The methods of measuring materials shall be such that the proportion of water to cement can be closely controlled during the progress of the work and easily checked at any time by the architect or his representative.

To avoid unnecessary or haphazard changes in consistency, the aggregates shall be obtained from a source which will insure uniform quality and grading during any single day's operation, and they shall be delivered to the work and handled in such a manner that variations in moisture content will not interfere with the steady production of concrete of a reasonable degree of uniformity.

Tests of Concrete

Frequent tests will be made by the architect throughout the work to determine the quality of concrete being produced. These tests will be made at the expense of the owner and will, in general, be made on 6 x 12 in. concrete cylinders loaded in compression at ages of 7 and 28 days, in accordance with the Standard Method of Making and Storing Specimens of Concrete in the Field (Serial Designation: C31-21) of the American Society for Testing Materials.

The contractor shall cooperate in every way to the end that concrete of the desired quality be obtained. He shall provide at cost, such housing as may be required for testing equipment and storage of test specimens; such cost to include only labor and materials actually used.

Portland Cement

Portland cement shall conform to the Standard Specifications and Tests for Portland Cement of the American Society for Testing Materials (Serial Designation: C9-21).

Fine Aggregate

Fine aggregate shall consist of natural sand having clean, hard, strong, durable, uncoated grains and free from injurious amounts of dust, lumps, soft or flaky particles, shale, alkali, organic matter, loam, or other deleterious substances. The sand shall be of such sizes that it shall all pass a ⅜-in. sieve, at least 15 per cent shall be retained on the No. 8 sieve, and the fineness modulus shall not exceed 3.50.

Coarse Aggregate

Coarse aggregate shall consist of gravel, crushed stone, crushed air-cooled blast-furnace slag weighing not less than 70 lb. per cu. ft. or other approved inert materials, having clean, hard, strong, durable, uncoated particles free from injurious amounts of soft, friable, thin, elongated or laminated pieces, alkali, organic or other deleterious matter. Coarse aggregate shall not have more than 10 per cent finer than the No. 4 sieve and the maximum size shall not be greater than will permit proper placement.

Storage of Aggregate

Aggregate shall be so stored as to avoid inclusion of foreign materials. Frozen aggregate or aggregate containing lumps of frozen material shall be thawed before using.

Water

Water for concrete shall be from the Chicago water supply or other approved source.

Mixing Concrete

The concrete shall be thoroughly mixed in a batch mixer of approved type. The mixer shall be equipped with suitable charging hopper. A water-storage and water-measuring device shall be provided. The mixing of each batch shall continue for at least one minute after all the materials are in the mixer during which time the mixer shall rotate at a peripheral speed of approximately 200 ft. per minute.

Depositing Concrete

Concrete shall be handled from the mixer to the place of final deposit as rapidly as practicable and in a manner that will prevent segregation of the ingredients. It shall be deposited in the forms as nearly as practicable in its final position to avoid rehandling. Concrete as it is deposited shall be puddled by means of suitable tools until forms are completely filled and reinforcement and embedded fixtures thoroughly incorporated in the mass.

Water shall be removed from excavations before the concrete is deposited, unless otherwise directed by the architect.

Concrete when deposited, shall have a temperature of not less than 40 deg. F. and not more than 120 deg. F. Concrete shall be deposited continuously and as rapidly as practicable until the unit of operation, approved by the owner's representative is completed.

In freezing weather suitable means shall be provided for maintaining the concrete at a temperature of at least 50 deg. F. for not less than 72 hours after placing, or until the concrete has thoroughly hardened. The methods of heating the materials and protecting the concrete shall be approved by the architect. Salt, chemicals, or other foreign materials shall not be mixed with the concrete for the purpose of preventing freezing.

Protection of Concrete

Exposed surfaces of concrete shall be protected from drying for a period of at least 7 days after being deposited.

Basis for Water-Ratio Specifications

It will be noted in the foregoing specifications that no proportions for cement, fine and coarse aggregates are stated, such as 1:1½:3, 1:2:4, etc., as in the common form of specification for concrete. The main requirements are that the water content in the mixture shall not exceed a stated amount per bag of cement used, and that the concrete shall be not wetter than a given consistency as determined by the so-called "slump test".[2] No particular grading requirements are stated for either the fine or coarse aggregates, and the main requirements are that both aggregates shall be clean and durable.

Under this specification the contractor may use any proportion of fine and coarse aggregates desired, except that the ratio of coarse to fine shall be not less than 1, nor more than 2. In other words, there must be at least as much coarse aggregate as fine aggregate in the mix but there must not be more than twice as much coarse aggregate as fine aggregate. In no case, however, can the contractor use more than the stated amount of water per bag of cement. If he wishes to produce a wetter concrete he obtains the desired result, not by adding more water, but by reducing the amount of total aggregate. This, of course, results in a higher cement content per cubic yard of finished concrete. Similarly, if a dryer concrete is desired either more aggregate is added to the mixture, or the water content may be reduced, in which case the cement content may likewise be reduced. In all cases, however, the proper relation of volume of water to volume of cement must be maintained and the right consistency of concrete must be used as determined by the slump test. It is assumed that if these requirements are fulfilled, the desired compressive strength will be obtained, irrespective of the characteristics of the cement, the temperature of the concrete during curing, the characteristics of the aggregate, the amount of work performed in placing and other variables incident to concrete construction.

Unquestionably, the attempt to control the strength of concrete by specifying the maximum amount of mixing water permissible is one of the most advanced steps in the production of better concrete that has been taken in recent years and, undoubtedly, it is highly important that the water content of the concrete be rigidly controlled. Because the water-ratio specification is at least aimed in the right direction and for that reason will be given more and more consideration, it is highly important that the basis for this specification be fully understood, its limitations studied and the necessary precautions exercised in its application.

If a water-ratio specification, such as just quoted, is used without proper understanding of its limitations the best results will not be obtained for other factors in addition to the mere relation of water to cement have considerable to do with the production of concrete of suitable quality and strength.

The basis for the water-ratio specification is largely the extended series of tests conducted under the able direction of Prof. D. A. Abrams, formerly of the Lewis Institute, Chicago. These tests are perhaps the most extensive ever conducted on concrete. Unusual thought and care were used in the entire laboratory procedure and great credit is due Professor Abrams and his laboratory personnel for the character of the investigational work performed.

Upon analyzing thousands of laboratory test results obtained from compression tests on concretes composed of wide ranges in proportions of water, cement, fine and coarse aggregate, the aggregates, for the most part, being

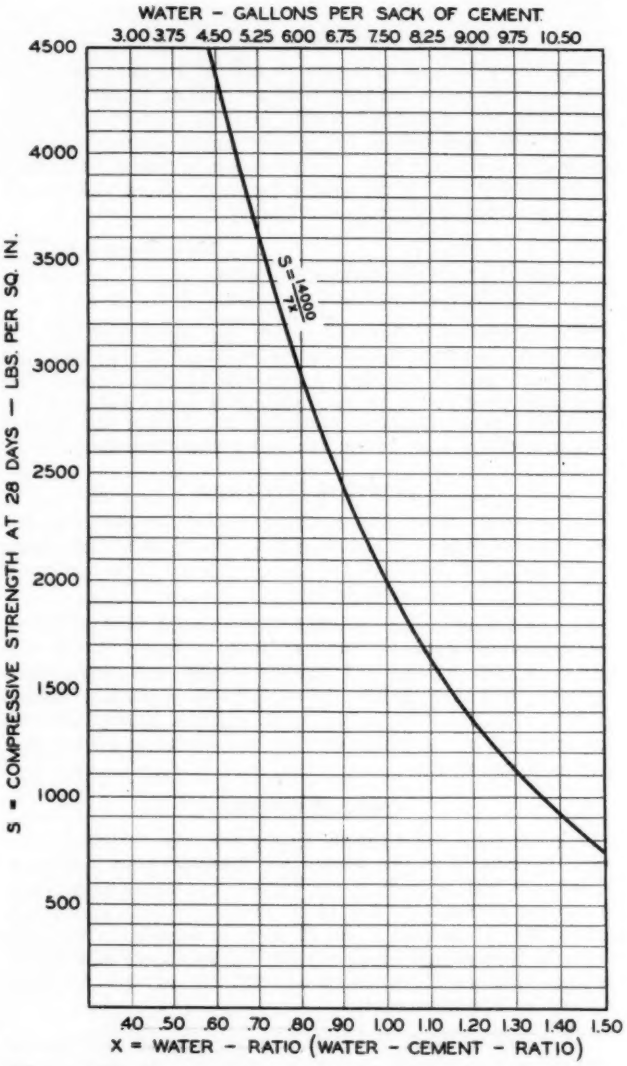

Fig. 1—Effect of quantity of mixing water on the strength of concrete. Curves are based on average values from nine different series of tests made over a period of four years. Tests made on about 50,000 6 by 12 in. cylinders at 28 days

from the same sources, there has been stated by Professor Abrams, a general law giving the relations between the compression strength of concrete and the so-called "water-

2. **Slump Test.** The slump test for consistency, standardized by the A. S. T. M. (D138-26T) consists of molding the concrete in a truncated cone mold 8 in. in diameter at the base, 4 in. at the top and 12 in. in height. The mold is immediately withdrawn after filling with concrete and the amount which the concrete subsides is known as the "slump."

ratio" or more properly, the "water-cement-ratio." This general law is as follows:

$$(1) \qquad S = \frac{A}{B^x}$$

Where S = Compressive strength of concrete.

A and B are constants which depend upon the particular conditions of the test such as the quality of cement used, age of the concrete, curing conditions and a number of other variables.

x = Water-ratio which is defined as the ratio of volume of water to volume of cement used in the mixture.

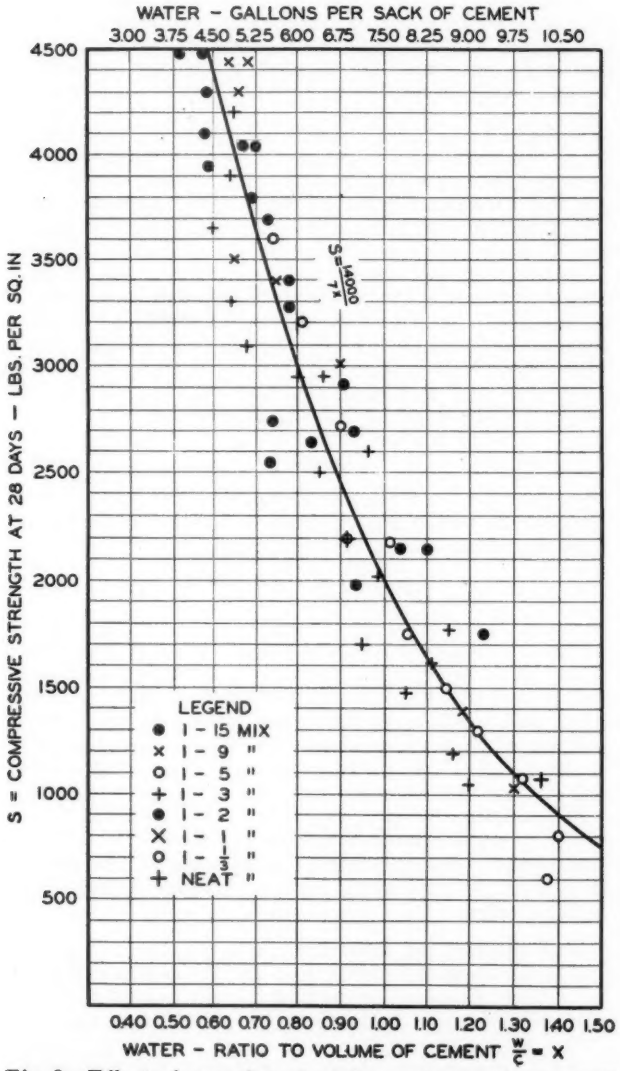

Fig. 2—Effect of quantity of mixing water on the strength of concrete. Compression tests of 6 x 12 in. cylinders at age of 28 days. Each value is the average from five tests.

For the particular conditions of the tests at the Lewis Institute this general equation becomes:

$$(2) \qquad S = \frac{14{,}000}{7^x}$$

And it is from this equation that the quantities given in the first paragraph of the water-ratio specification on page 2 have been derived, namely, 6 gallons of water per bag of cement corresponding to 2900 lbs. per sq. in., and 7½ gallons corresponding to 2000 lbs. per sq. in. compressive strength at 28 days.

If equation 2 were plotted, it would appear as shown in Figure 1 and the curve representing this equation would strike an average of the thousands of test results obtained in the Lewis Institute laboratory. It must be understood, however, that by no means would all the test values coincide with this curve. As a matter of fact, if all of the results were plotted many of them would be far removed from the curve of average values. This is well exemplified in Fig. II where it will be noted that for consistencies around 1.0 and less, which are those most used for concrete construction, the range between the maximum and minimum results obtained is a high percentage of the average. For instance, with a water-ratio of 1.0 the individual results show the possibility of a variation in strength of 1500 up to 2700 lbs. per sq. in. with an average a little over 2000. Here is a range of 1200 lbs. per sq. in. in strength and the maximum strength, 2700 lbs. per sq. in. is 1.8 times the minimum of 1500 lbs. per sq. in. Other series of tests made under laboratory conditions show a much wider range of values than in Fig. II.[3]

It must be remembered that the test results in Fig. II were obtained under the most rigid laboratory control, and every precaution was exercised to obtain as nearly uniform results as possible. Moreover, variables due to the personal equation of different operators were largely eliminated. When concrete tests are made with different materials and in different laboratories a still wider divergence of results from the average is obtained. This is well illustrated in Fig. III. This statement is made, not at all to discredit the laboratory procedure or the general law which has been obtained, but rather to show the danger of accepting a general law as applicable to all materials and all conditions of concrete manufacture and test.

These variations from the average law obtained at the Lewis Institute should not be surprising for it must be evident that if one brand of Portland cement is considerably higher in strength than another brand, the water-ratio curves of concrete containing these different brands will be different, the high testing cement probably showing a higher compression strength in the concrete. Similarly, it must be evident that since the temperature under which concrete hardens plays a most vital part in controlling its compressive strength, the water-ratio curve for concrete hardened under low temperatures must be considerably lower than that for concrete hardened under high temperatures. Again, since it is known that the strength of particles in the fine aggregate and their gradation often control the mortar strength in laboratory tests, the water-ratio curves for concrete containing two different sands are very apt to

3. Bulletin 137, "The Strength of Concrete, Its Relation to the Cement, Aggregates and Water," by Arthur N. Talbot and Frank E. Richart. Enginering Experiment Station, University of Illinois.

be quite different. Similarly, the coarse aggregate should show some effect and the curve between water-ratio and compressive strength for one coarse aggregate will very likely be higher than that of another coarse aggregate, due

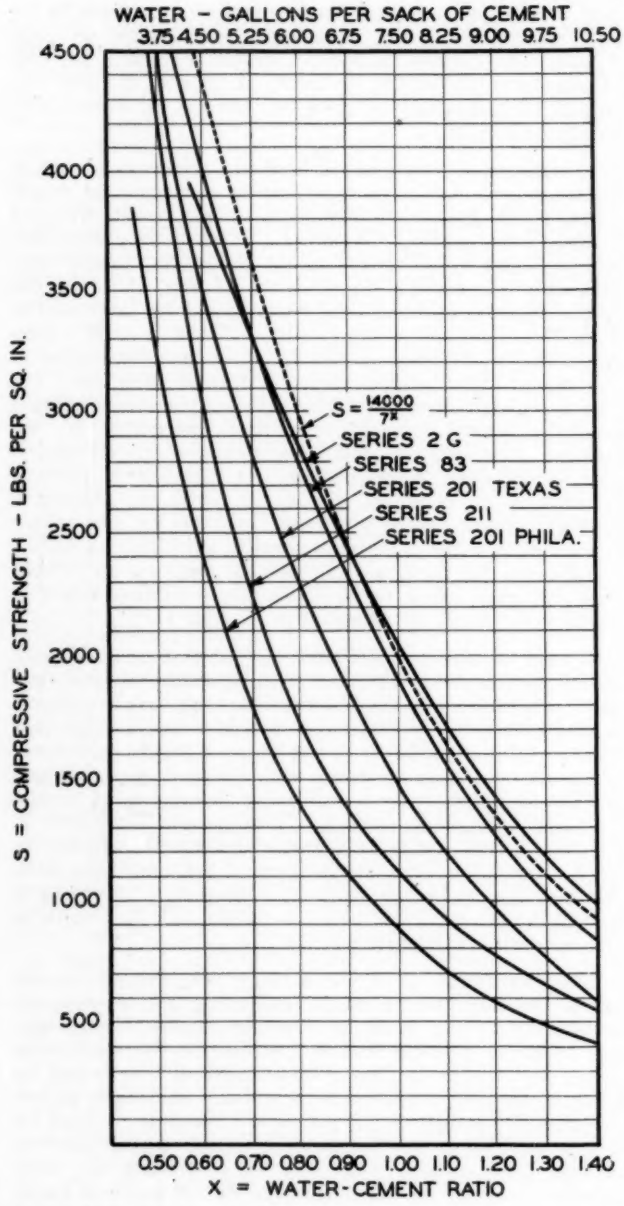

Fig. 3—Water-cement ratio and compressive strength replotted from Univ. of Ill. Eng. Exp. Sta. Bull. No. 137. Abrams' curve added.

entirely to the difference in the nature and gradation of these aggregates.

This all serves to emphasize the fact that the Lewis Institute water-ratio curve, expressing the relation between compressive strength and water-cement-ratio, is only an average curve of the Lewis Institute tests and it holds only so long as the conditions under which a particular set of tests are made agree with the average conditions existing in the tests from which this curve was derived. If the test conditions vary from these average conditions the compressive strength results may be expected to fall either above or below the line expressing the average results. For any given set of conditions a water-ratio curve will result which, although not coinciding with that shown in Fig. I, will follow it closely in form and will lie either above or below it. *The water-ratio compressive strength relation is not a single relation. There is a series of such relations each applying only to a particular set of conditions. In view of the fact that the average curve cannot be relied upon to give strength results entirely independent of the conditions under which the results are obtained, it is quite insufficient to use a water-ratio specification of the type quoted without some modification. The use of the same water-ratio does not necessarily produce concrete of the same strength.*

In Fig. IV are shown results obtained in the construction of the Portland Cement Association building in which the water-ratio specification was used. These results are very disappointing because of their wide range and they do not tend to reassure one of the reliability of a simple form of water-ratio specification for controlling the strength of concrete. It is evident that variables exist in the field control of concrete which are not adequately controlled by the water-ratio specification. Surely it should be possible to write a specification for concrete which will insure much better control over its strength than indicated by the results in Fig. IV, and such a specification must not ignore the important variables which are known to exist.

Summary

Summing up the foregoing discussion, it is quite evident that the water-ratio curve originally established at the Lewis Institute and expressed by the formula:

$$S = \frac{14{,}000}{7^x}$$

is only an average relation which does not apply to all conditions. The water-ratio compressive strength relation instead of being a single definite relation is really a series of relations which might be shown graphically by a series of curves of the same general shape as the Abram's curve but occupying a belt or zone on each side of this curve. *Each of these individual curves would apply for a particular set of conditions but not for others.* The water-ratio compressive strength relation would be expressed by a different curve if there was a difference in any one of the following factors, some of which have a slight effect and others a decided effect:

(a) Strength of cement.
(b) Grading and strength, surface characteristics and shape of either fine or coarse aggregate.
(c) Different combinations of fine and coarse aggregate.
(d) Temperature of concrete during the curing period.
(e) Character of curing and perhaps other conditions.

In view of the above variables it seems unwarranted to expect great uniformity in strength of concrete proportioned by the use of a general average water-cement-ratio-compressive-strength relation. Moreover, failure to recognize the inadequacy of the general water-ratio relation will lead to lack of economy. This is so because it is necessary that the weakest concrete produced be strong enough and of high enough quality for the work it must perform. In view of the present high variation in strength obtained with the simple uncorrected water-ratio method the maximum strengths are often double and sometimes quadruple the minimum (See Fig. IV), and the concrete must, of necessity, be over-designed in order that the lowest strength obtained be high enough. It is recognized that the expense of attaining more uniform strength must be balanced against the extra cement necessary when less precise means of control are used.

Correction for Temperature

The effect of temperature on the strength of concrete has not been given the full investigation which its importance certainly warrants. It is common knowledge that the strength of concrete is reduced by low temperatures and is increased by high temperatures. This point was recognized by Arthur R. Lord in controlling the concrete used on the Wacker Drive in Chicago. Mr. Lord, in his paper before the American Concrete Institute in February, 1927, made the following statement:

"We found on Wacker Drive that one degree change in temperature was roughly equal to 50 lbs. per sq. in. change in strength at 28 days. With weaker concrete I should expect a less effect. As between 75 deg. average 28-day temperature (July) and 55 deg. (May and October) this means a loss of 1000 lbs. per sq. in, in strength. No precautions are ordinarily taken in the field at this time of year and yet, if our showing is at all generally applicable,

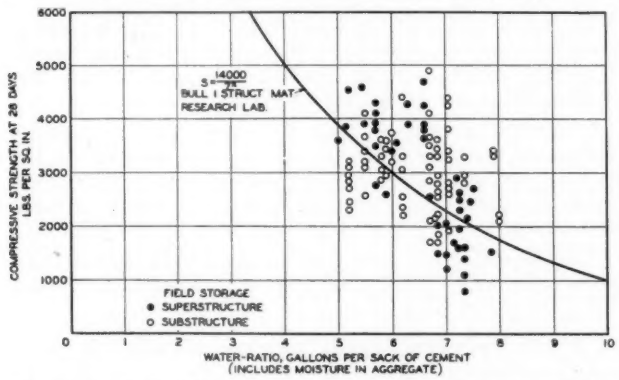

Fig. 4—Test results and strength—Law curve upon which specification is based. From Eng. News-Record, Vol. 96, No. 17.

here is a variation in strength equal to a change of 0.15 in the water-cement ratio or of 1 gal. of water per sack of cement. Furthermore, our 6 and 12-month tests, while too few in number to be at all conclusive, indicate that concrete placed under cool temperatures in April and May never catches up with that placed under mid-summer temperatures. Our whole study of the problem is inconclusive for the reason that our data were all that of field tests with all the variables operating at once. Our tests do indicate the need of adequate laboratory tests under controlled temperatures to investigate this variable."

As Mr. Lord states, in view of the fact that other variables were operating to affect the strengths obtained, his tests are not conclusive but merely indicate the fact that temperature plays an important part in controlling the strength of concrete in the field and should be fully allowed for in any attempt to control the strength of concrete during construction.

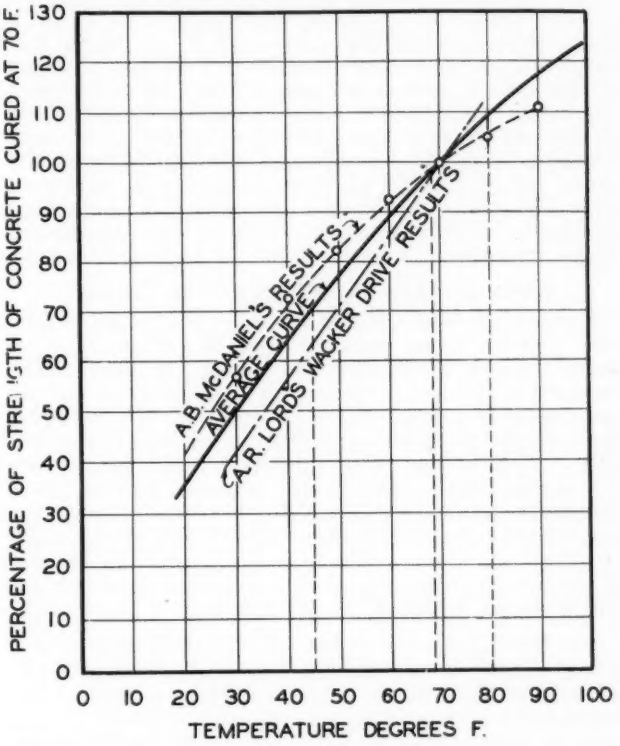

Fig. 5—Effect of Curing Temperatures on Compressive Strength of Concrete at 28 Days

Plotted from results shown in Fig. 15, Bulletin 81, Univ. of Ill.—"Influence of Temperature on Strength of Concrete," by A. B. McDaniel, and from A. R. Lord's "Notes on the Wacker Drive" presented before the American Concrete Inst., 1927

A series of tests to determine the effect of temperature on the compressive strength of concrete was made at the University of Illinois Engineering Experiment Station and reported by A. B. McDaniel in Bulletin 81 entitled, "Influence of Temperature on the Strength of Concrete." The graph shown in Fig. V was plotted from McDaniel's and Lord's results. The Illinois tests were made under carefully controlled temperature conditions and other variables were probably kept more constant than would be possible when field controlled. It will be noted that there is a fair agreement of the Wacker Drive results with McDaniel's results, the Wacker Drive curve, however, showing a more severe temperature effect than the McDaniel curve.

The following example will illustrate the practical application of these temperature correction curves. It will

be assumed that the average curve is correct. If the strength of the concrete cured under a temperature of 68°F. was 2500 lbs. per sq. in., the expected strength of concrete cured under 40°F. would be:

$$\frac{2500}{98} \times 63 \text{ or } 1610 \text{ lbs. per sq. in.}$$

Similarly, if the concrete were cured at 80°F. the expected strength would be:

$$\frac{2500}{98} \times 108 \text{ or } 2760 \text{ lbs. per sq. in.}$$

This range in temperature, from 40°F. to 80°F., thus causes a range in strength of 1610 to 2760 lbs. A range of temperature such as this often occurs on an extended job and it is evident that a wide range in strengths is to be expected unless a proper correction is made in the mix, depending upon the temperatures anticipated during the curing period. Surely an error in results as serious as above indicated should not be ignored and the water-ratio specification would be improved by the inclusion of a proper means for temperature correction.

Effect of "Gain in Water" During Curing

There is one other variable affecting the strength of concrete which is often overlooked and this is the "gain in water" content in the concrete during the construction operation. The water portion of the concrete has the lowest specific gravity of the entire mass. It, therefore, tends, naturally, to rise to the top as the heavier particles settle. There is, thus, always the tendency of the top portion of the concrete mass to gain in water content during the placing operation. This is to be avoided as much as possible if uniformity in strength is to be attained. The use of as dry a mix as the work will permit and the use of periodic dry mixes to absorb the excess moisture in the top layers are means which are effective.

Mis-Application of the Water-Ratio Curve

In a number of instances the water-ratio curve has been mis-applied from the very beginning, largely because the specification as written ignores the fact that the water-ratio strength relation as expressed by Abrams' curve is only one of a series of similar relations governed by the particular conditions existing for any given concrete. Under this specification, contractors in comparing the different aggregates merely determine the amount of water required to produce a given slump in the concrete made with the respective aggregates. If one aggregate requires more water than another to produce the same slump, automatically, according to this specification more cement must be added or less aggregate be used to maintain the required water ratio. This procedure, although permitted by the specifications is far from accurate for, in the first place, the sole measure prescribed for determining the workability of the concrete is the slump test. The slump test is now recognized as being a very rough indication of workability and not at all applicable to certain kinds of aggregates, notably the large rough angular aggregates. The flow table[4] is a much more sensitive and accurate device. Another inaccuracy in this method is its failure to recognize that with different aggregates different water-ratio compressive strength curves may be obtained. In other words, the same strengths are possible with different aggregates, using somewhat different water-ratios. *The only safe way to compare the relative value of different aggregates is by means of suitable strength tests of concrete made of these aggregates.* The particular strength test selected should simulate the kind of stress to which the concrete is to be subjected in service. Thus, for concrete roads a transverse test should be employed and not a compression test.

There are other factors which seem to make for variation in strength and quality of concrete controlled by the water-ratio specification. Evidently the specification does not adequately insure the use of the correct amount of water in the concrete nor does it insure curing conditions which are like those used in the tests from which the water-ratio curve was obtained. The control of extremely fine material in the fine aggregate is likewise inadequate and the use of economically graded aggregates is not required.

Suggested Modified Water-Ratio Specification

In an effort to overcome some of the difficulties found in the present water-ratio specification, and in order to make the present comments on this specification as constructive as possible, the following modified specification is offered merely as a step forward in the production of more economical and more uniform concrete. Perhaps other improvements in the specification will suggest themselves to others.

SPECIFICATION FOR CONCRETE AND CONCRETE MATERIALS

Water-Cement Ratio

The concrete shall be proportioned to give the necessary workability as determined by the flow table and specified in Table —— with a water content not greater than that determined by the engineer as follows:

1. Preliminary tests shall be made for compressive strength of concrete with the materials to be used on the work. The tests shall include several water-ratios from which corresponding strengths may be plotted. Curing shall be conducted in the same manner as on the job.

2. The strength results thus obtained shall be corrected for temperature, making use of the diagram shown in Fig. V as follows:

Corrected strength equals strength obtained in tests multiplied by $\frac{B}{A}$

Where A = Ordinate to curve for average temperature during curing of test specimens.
B = Ordinate to curve for anticipated average curing temperature on the work.

4. **Flow Test.** This test described under "Standard Method of Making Compression Tests of Concrete," Serial Designation C39-25, of the A. S. T. M., is made by placing a metal mold in the shape of a frustum of a cone 6½ in. in top diameter, 10 in. in bottom diameter, 5 in. deep, on the table of the flow apparatus. The fresh concrete is placed in the mold in a standard manner. The top is struck off with a trowel and the mold immediately removed by a steady upward pull. The flow table is then raised one-half inch and dropped 15 times in about ten seconds by means of a suitable cam and crank. The spread of the fresh concrete due to this treatment expressed as a percentage of the original diameter of the cone is the "flow."
The following approximate relation between "Slump" and "Flow" as described herein may be of interest:

"Slump"	"Flow"
1 in.	140
3 in.	175
5 in.	195
7 in.	210

3. Plot temperature corrected strengths obtained as in paragraph 2 and with these points draw a water-ratio curve similar to Abrams' curve.

4. Select from this corrected water-ratio curve the water-ratio necessary to produce the required strength.

5. Strength tests made during the progress of the work shall be used by the engineer as a further guide in the determination of the water-ratio required to produce the desired strength.

The remaining portion of the specification may follow closely that already quoted on pages 2 and 3 except that

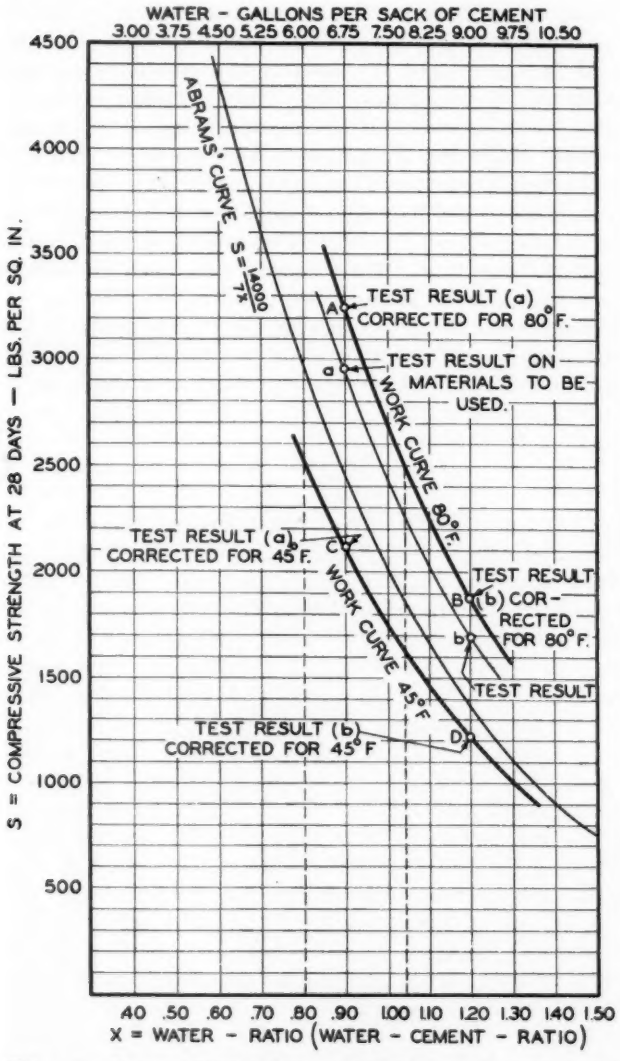
WATER - GALLONS PER SACK OF CEMENT
3.00 3.75 4.50 5.25 6.00 6.75 7.50 8.25 9.00 9.75 10.50
4500
4000
3500
3000
2500
2000
1500
1000
500
S = COMPRESSIVE STRENGTH AT 28 DAYS — LBS. PER SQ. IN.
ABRAMS' CURVE
S = 14000 / 7x
TEST RESULT (a) CORRECTED FOR 80° F.
A
TEST RESULT ON MATERIALS TO BE USED.
a
WORK CURVE 80° F.
TEST RESULT (a) CORRECTED FOR 45° F.
C
TEST RESULT (b) CORRECTED FOR 80° F.
B
b
WORK CURVE 45° F
TEST RESULT
TEST RESULT (b) CORRECTED FOR 45° F
D
.40 .50 .60 .70 .80 .90 1.00 1.10 1.20 1.30 1.40 1.50
X = WATER - RATIO (WATER - CEMENT - RATIO)

Fig. 6—Curve illustrating application of water-ratio theory to particular conditions.

the flow determined by the flow table should replace the slump. An elutriation test should also be required for the fine aggregate, better grading requirements are needed for both fine and coarse aggregates, and other minor changes might also be made. Apparently, too, the water should be more definitely controlled.

Numerical Example

As a numerical example of the procedure to be followed under this modified specification let it be assumed that the work is of such a nature that a compressive strength of 2500 lbs. per sq. in. is desired with a consistency corresponding to a flow of 180 (approximate slump of 7 inches). As the first step in this procedure, preliminary tests are made on the concrete using materials proposed for the work. Water-ratios selected for use in the tests are 0.90 and 1.20, and the strengths obtained are 2950 and 1700 respectively, plotted at *a* and *b*, Fig. VI. The average curing temperature in the tests was 68°F. It is anticipated that by the time the work starts an average temperature of 80°F. will be reached. From Fig. V temperature corrections are obtained from which it is determined that with a temperature of 80° the strengths of 2950 and 1700 respectively would be corrected to

$$\frac{2950}{98} \times 108 = 3250$$

$$\frac{1700}{98} \times 108 = 1880$$

These points are plotted on Abrams' curve as points A and B and through them a water-ratio curve is drawn parallel to Abrams' curve. From this curve the proper water-ratio may be selected to give the required strength of 2500 lbs. per sq. in. For these particular conditions this water-ratio is seen to be 1.04 or 7.8 gal. of water per bag of cement.

Had Abrams' uncorrected curve been used, the water-ratio required to produce a strength of 2500 lbs. per sq. in. would have been approximately .90 or 6.7 gal. of water per bag of cement. Suppose the job lasts until winter when an average temperature of 45°F. is expected. For such an anticipated average temperature the water-ratio would have to be changed. The test strength results, *a* and *b*, corrected for a temperature of 45°F. would then be as follows:

$$\frac{2950}{98} \times 70 = 2110$$

$$\frac{1700}{98} \times 70 = 1220$$

From the curve drawn through these points parallel to Abrams' curve and labeled C and D in Fig. VI, it is seen that a water-ratio of 0.80 should be used corresponding to only 6 gal. of water per bag of cement. If the proper corrections are not made in the water-ratio curve for the range in temperature of 45° to 80°F., a variation in strength of 1000 pounds per sq. in. would have to be expected.

The foregoing may seem like a highly complicated process. As a matter of fact, it is extremely simple and involves just two important steps which are not recognized by the present water-cement-ratio specification, namely, preliminary strength tests are required to establish the particular water-ratio curve applicable to the materials to

(*Continued on page* 14)

The President's Page

It is with deep personal regret and a realization of the loss sustained by the Association that we have been made aware of the resignation of Mr. Arthur F. King as chairman of the Manufacturers' Division. He has also resigned his position as director of sales with the Marion Steam Shovel Company. The state of Mr. King's health is such as to necessitate his being relieved for an extended period of time of all duties and responsibilities. While there is no doubt as to his ultimate recovery, it can be most speedily and surely brought about by complete relaxation for an indefinite length of time.

The Manufacturers' Division and our Association in its entirety has benefited by the stimulus of the inspiring and intelligent enthusiasm which Mr. King has so constantly manifested for our common interest. He has sympathetically appreciated and understood our aims and ideals and has evidenced his support of our purposes in no uncertain manner. It was heartily agreed at Detroit that the Manufacturers' Division had acted wisely in selecting him for its chairman this year, and it was with pleasurable anticipation that we looked forward to his able support and counsel in the work which lies ahead of us. The active members surely join with our manufacturing brethren in wishing him a full and speedy recovery and cling to the hope that he will return to some occupation which will bring him again within the membership of this Association.

The six Vice-Chairmen have been requested by mail vote to select one of their number to act as Chairman of the Division until the expiration of Mr. King's term of office. While a selection might well be made by the Board of Directors of the Division, the choice would necessarily have to be made from one of the six Vice-Chairmen; but in order to save time and simplify the process, it is assumed that the Board of Directors will approve such choice as may be made by the Vice-Chairmen. There are several plans of mutual interest to producers and manufacturers which must be delayed until the acting Chairman is selected and consequently the saving of time in this procedure is of considerable value.

* * * * * *

Mr. Goldbeck and your President spent a most enjoyable and interesting day in Youngstown, Ohio, on May 27th as the guests of the Western Pennsylvania Stone Producers' Association, of which Mr. William M. Andrews is the President and Mr. J. C. King the Secretary-Treasurer. Throughout the morning and well into the afternoon matters of interest to the local association, as well as to the National, were discussed and policies determined. It will be recalled that this association was the first to pledge six thousand dollars annually toward the support of the Bureau of Engineering, and by their whole-hearted interest and enthusiasm largely contributed to its ultimate establishment. Their financial support continues unabated, and the National Association may well be proud of such loyal group support.

In the latter part of the afternoon we visited the plants of the Bessemer Limestone and Cement Company, of which Mr. Kanengeiser was Vice-President and General Manager until it was recently purchased by the Standard Slag Company; the Carbon Limestone Company, with which our Director, Mr. King, is connected and of which Mr. Earnshaw is Vice-President, and the Lake Erie Limestone Company, of which Mr. Andrews, a member of the Executive Committee, is Secretary and Treasurer. These are interesting operations, well managed and conducted. Their visitors were most hospitably entertained, both at the plants and at the meeting in Youngstown, and were speeded on their way with the encouraging message that if further financial assistance was needed, the producers of Western Pennsylvania were standing ready to do more than their part, now, as they have in the past.

* * * * * *

It is gratifying to know that the first issue of six thousand copies of Bulletin No. 1 on "The Bulking of Sand and Its Effect on Concrete" has been entirely exhausted. A second edition is now on the press. So wide a distribution of its scholarly discussion of a subject of interest to engineers and contractors cannot but be helpful to the industry. We respectfully submit that no company can afford to fail to have these bulletins, as they will be issued from time to time on various subjects, freely distributed to the engineers, architects, contractors and road-building officials within its local territory. All engineers, particularly those engaged in road building, will welcome the receipt of articles on timely topics from such an authority as Mr. Goldbeck and cannot but be appreciative of the courtesy of any company in thus thoughtfully remembering them. When all of our members appreciate the promotional and advertising value inherent in the mailing of these bulletins, we believe that subsequent issues will be several times larger, with increased benefit to our industry. The engineering profession is alert and receptive to new ideas and methods and clearly seeks to maintain contact with research and scientific investigation. In so far as our Bureau of Engineering may assist in furthering this scientific alert-

(*Continued on page* 14)

National Safety Competition Awards Announced

Winners of the National Safety Competition, in which more than 250 mines and quarries in 30 States participated in 1926, were announced today by the United States Bureau of Mines, Department of Commerce. The winning mines and quarries in this nation-wide industrial safety contest, held annually under the auspices of the Bureau of Mines, are presented with the bronze trophy "Sentinels of Safety," donated by the *Explosives Engineer* magazine.

Notable accomplishments in the production of large mineral tonnages with no loss of time occasioned by accidents were revealed by the detailed statistical reports furnished the Bureau by the competing companies. A zinc and lead mine in Kansas operated 300 days and worked 206,489 man-hours without an accident involving loss of an employe's time. A Missouri zinc mine and 14 large quarries, located in West Virginia, Pennsylvania, Alabama, Indiana, Ohio, Kansas, California, Virginia, and Michigan, also operated through the year with no loss of time due to personal injuries. The competition was one of the largest industrial safety contests ever held, and involved the tabulation of all accidents occurring during the course of 95,000,000 man-hours of labor. It required the preparation of accident statistic reports on a uniform, detailed basis which allows a more exhaustive study of the causes of accidents than has heretofore been possible. An encouraging feature of the competition was a substantial reduction in the accident rates of the winning companies in 1926, as compared with the previous year's contest.

Secretary Hoover, of the Department of Commerce, in addressing congratulatory letters to the winning mines and quarries, emphasized the importance of the American mining industry attaining world leadership in accident prevention as it has already attained such leadership in the production of mineral tonnages.

The more than 250 mines and quarries participating in the competition were divided into five groups: anthracite

Scott Turner, Director of Bureau of Mines and Secretary Hoover, with bronze trophy, "Sentinels of Safety"

mines, bituminous coal mines, metal mines, mines producing non-metallic minerals, and quarries or open pit mines. A replica of the trophy is awarded to the mining operation in each group sustaining the smallest loss of time from accidents in proportion to total time worked during the year. Determination of the winners was made by a jury of award comprised of officials of various mining and quarrying associations, the National Safety Council, and the American Federation of Labor, based on a tabulation of mine accident data prepared by the Bureau of Mines. A feature of the competition is the awarding of a certificate of honor, signed by the Director of the Bureau of Mines, to every employee of each of the winning mines and quarries for their share in the low accident records made by their companies.

The winner in the anthracite group is the Highland No. 6 mine, Jeddo, Luzerne County, Pa., operated by the Jeddo-Highland Coal Company. In this group, honorable mention was accorded the Highland No. 2 anthracite mine and the Jeddo No. 7 mine, of the same company, and also located at Jeddo; to the Upper Lehigh anthracite mine, Upper Lehigh, Pa., operated by the Hazle Brook Coal Company; and to the Pine Hill mine, Minersville, Pa., operated by the Pine Hill Coal Company.

In the bituminous coal mining group, the trophy was won by the No. 6 coal mine of the United States Coal and Coke Company at Gary, MacDowell County, W. Va. Honorable mention was given to four other mines operated by this company, viz.: No. 8 and No. 7 mines, at Elbert, W. Va., and No. 5 and No. 4 mines, at Thorpe, W. Va.

In the underground metal mining group, the Muncie zinc and lead mine, operated by the Federal Mining and Smelting Company, at Baxter Springs, Cherokee County, Kansas, was adjudged the winner. Honorable mention was accorded the Velten zinc mine of the Eagle-Picher Lead Company, at Pierce City, Mo.; the Wilbur zinc and lead mine of the Commerce Mining and Royalty Company, at Treece, Kansas; the Armour No. 2 iron mine of the Inland Steel Company, at Crosby, Minn.; and the Lucky Bill lead and zinc mine of the Federal Mining and Smelting Company, at Cardin, Okla.

In the group of underground mines producing non-metallic minerals, the trophy was awarded to the Grand Rapids gypsum mine of the Beaver Products Company, Inc., at Grand Rapids, Mich. Honorable mention was given the Ft. Dodge gypsum mine of the United States Gypsum Company, at Ft. Dodge, Ia.; the Manheim No. 5 cement rock mine of the Alpha Portland Cement Company, at Manheim, W. Va.; the Crystal City sand mine of the Pittsburgh Plate Glass Company, at Crystal City, Mo.; and the *Templeton limestone mine of the Templeton Limestone Company, at Templeton, Pa.*

In the quarry and open pit mine group, the trophy was awarded to the No. 5 and 6 limestone quarry of the North American Cement Corporation, at Martinsburg, W. Va. Honorable mention was accorded the following-named quarries; West Coplay limestone quarry of the Lehigh Portland Cement Co., West Coplay, Pa.; Birmingham limestone quarry of the Lehigh Portland Cement Co., Birmingham, Ala.; *Louisville cement rock quarry of the Louisville Cement Co., Speed, Indiana;* United States Gypsum Company limestone quarry, Genoa, Ohio; Kansas Portland Cement Company limestone and shale quarry, Bonner Springs, Kansas; Ash Grove Lime & Portland Cement Company limestone and shale quarry, Chanute, Kansas; Mitchell limestone quarry of the Lehigh Lime Company, Mitchell, Indiana; Cowell Portland Cement Company limestone quarry, Cowell, Calif.; Nos. 1 and 2 high calcium limestone quarry of the M. J. Grove Lime Company, Stephens City, Va.; Dexter Portland Cement Company cement rock quarry, Nazareth, Pa.; Royal Blue Slate Company roofing and electrical slate quarry, Slatedale, Pa.; *Monroe, Michigan, limestone quarry of The France Stone Company, Monroe, Michigan;* Bellevue cement rock quarry of the Alpha Portland Cement Company, Bellevue, Mich.

Companies operating a coal mine employing 50 or more men underground, a metal or other mine employing 50 or more men underground, or a quarry or open pit mine employing 25 or more men in the pit were eligible to compete for the trophies. The trophy, which is the work of Begni del Piatta, designer of the Navy and Marine Memoriol to be erected in Washington, portrays in bronze a mother and child greeting the father upon his safe return from work. The names of the mines and quarries who win the right to hold the trophy for a year will be engraved on the pedestal. On the remaining sides of the pedestal are panels emblematic of coal mining, metal mining, and quarrying and open-pit mining.

Members of the jury of award were as follows:

H. Foster Bain, secretary, American Institute of Mining and Metallurgical Engineers, New York.
James F. Callbreath, secretary, American Mining Congress, Washington, D. C.
W. H. Cameron, managing director, National Safety Council, Chicago, Ill.
H. L. Gandy, secretary, National Coal Association, Washington, D. C.
A. T. Goldbeck, director, engineering bureau, National Crushed Stone Association, Washington, D. C.
William Green, president, American Federation of Labor, Washington, D. C.
A. J. R. Curtis, assistant to general manager, Portland Cement Association, Chicago, Ill.

The following congratulatory letter was addressed by Secretary Hoover to the winner in each group:

"The excellent safety record established by your company at one of its plants during the year 1926, as shown by the results of the National Safety Competition held under the auspices of the Bureau of Mines, is a matter for congratulation to your company and of encouragement to all persons interested in safety in the mineral industry. It is such work as is being done by your company and others that affords the best hope that the United States may lead the world in mine safety as it is already leading in mineral production. Our aim should be for progressively lower accident rates.

"The success of your efforts in safety work during the past year entitles your company to receive the 'Sentinels of Safety' trophy which is awarded to the leaders in the National Safety Competition. Also, since the prevention of accidents is dependent not only on the operators that produce our coal, iron, stone, and other minerals, but also on each employee of the mine or quarry, the Bureau of Mines will issue a Certificate of Honor to each man employed by your company in 1926 at the plant whose safety record is recognized by the award of the trophy."

N. C. S. A. MEMBERS RECEIVE HONORABLE MENTION IN NATIONAL SAFETY COMPETITION

It is with very real pleasure that we note from the announcement by the United States Bureau of Mines of the awards for the 1926 National Safety Competition that three members of the National Crushed Stone Association had such excellent safety records during 1926 as to warrant receiving an Honorable Mention in this competition. This honor was received, in the underground mine group, by the Templeton limestone mine of the Templeton Limestone Company at Templeton, Pennsylvania, and in the quarry and open pit mine group, by the Louisville cement rock quarry of the Louisville Cement Company, at Speed, Indiana, and the Monroe, Michigan, limestone quarry of The France Stone Company.

We wish to extend our hearty congratulations to these companies for the excellent safety records which they have established. It will be remembered that the cement rock quarry of the Louisville Cement Company at Speed, Indiana, was also accorded an Honorable Mention in the Competition for 1925, so they are to be doubly congratulated for so effectually continuing during 1926 their excellent record of 1925.

A CORRECTION

In publishing in the May issue of the Journal the list of our member companies who have entered the National Safety Competition for 1927, the Berlin quarry under The France Stone Company was printed in error and should be replaced by the Kenneth quarry. The Mt. Pleasant quarry listed under The General Crushed Stone Company should be listed under The France Stone Company, and the Akron quarry should be added to The General Crushed Stone Company. Also, the Lohrville quarry of the Universal Granite Quarries Company has entered the Competition since the publication of the list.

A portion of the face of the Monocacy Quarry at Birdsboro, Pa., operated by the John T. Dyer Quarry Co.

JOHN T. DYER QUARRY COMPANY MAKES RECORD BLAST

What is reported as being the largest blast ever fired in a stone quarry in the East was set off on May 30 at the Monocacy Quarry of the John T. Dyer Quarry Company, located three miles west of Birdsboro, Pennsylvania.

The populace of Birdsboro and surrounding country evidently turned out en masse for the event as it was estimated that the slopes opposite the quarry face and about a half mile distant were crowded with approximately ten thousand spectators, many of whom had come considerable distances. In fact, judging from the license tags of the cars parked in the vicinity, at least four states were represented.

A total of 169,000 pounds of dynamite was used in the blast in the form of large sticks, seven inches in diameter and twenty-four inches long, each stick weighing fifty pounds. These figures become more significant if we think of them in terms of one large stick of dynamite seven inches in diameter and over a mile and a quarter in length.

Probably for the first time in the history of quarry blasting in this country, well drill holes and a large coyote hole, or tunnel, were utilized in the same blast. The main tunnel was driven into the cliff a distance of 105 feet. Diverging from each side of the main tunnel there were six lateral tunnels, three on each side, giving a total tunnel footage of 430 feet.

The loading of the dynamite was directed by S. R. Russell, senior technical explosives expert of E. I. DuPont de Nemours and Company, and the shot was fired by L. P. Mahoney, director of sales of the same company. F. T. Gucker, general manager of the John T. Dyer Quarry Company, and William Kelly, superintendent, were in charge of the blast.

It was estimated that approximately 1,000,000 tons of rock were brought down and that it probably would not be necessary to fire another blast within two years.

The CRUSHED STONE JOURNAL
J. R. BOYD, Editor
A. T. GOLDBECK, Director, Bureau of Engineering

The National Crushed Stone Association

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COMMITTEE E-1 OF A. S. T. M. ORGANIZES SECTION ON COARSE SCREENS

We have recently been informed that there has been organized a Section on Coarse Screens, of the Sub-Committee on Size and Shape, of Committee E-1 of the American Society for Testing Materials, with the following personnel:

F. H. JACKSON, *Chairman*
U. S. Bureau of Public Roads, Washington, D. C.

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W. B. Howard	Howard and Morse
B. G. Shotton	Hendrick Manufacturing Company
J. M. Fuller or F. P. Hutchinson	Harrington and King Perforating Company
G. A. Disbro	W. S. Tyler Company

The President's Page

(*Continued from page* 10)

ness, we will have contributed something to our common good, as well as have advanced the interest of our industry along the soundest and most ethical lines. If your order has not already been sent to the Washington Office, either as an individual company or through a local association, it should be done immediately. You may be too late for Bulletin No. 1, but you will be in time for the next one. The cost, 10 cents per copy, including mailing charges, is too trivial to consider, and the immediate benefit to be derived by each company would justify its participating in this plan, even if the cost were ten times as great. It is so easy to form good resolutions, table their execution until a more convenient moment and then forget all about them. The safest plan and the wisest is to send in your order now.

Water-Ratio Specification for Concrete and Its Limitations

(*Continued from page* 9)

be used on the job, and, second, the proper adjustments are made in this curve for different temperatures to be expected during the progress of the work. The preliminary strength tests will form a proper basis for the economical selection of aggregates and proportions which is not offered by the present water-ratio specification and, moreover, much more uniform and consequently much more economical concrete should result through the use of the modified specification which recognizes some of the important causes for variation in the strength of the concrete.

The general law expressed by the water-ratio compressive strength relation is an important step in the production of concrete of high quality. It is hoped that the ideas expressed herein will contribute to make that law applicable to individual conditions and, thus, more satisfactory than in its present form.

Place Your Orders for Bulletin No. 1 Immediately

We are particularly pleased to be able to announce that as this issue of the Journal goes to press, approximately six thousand copies of Bulletin No. 1 have been purchased by our members for distribution in their respective territories.

This figure, however, could easily be made twelve thousand if each one of our members would take advantage of this opportunity to place in the hands of the engineers, contractors, architects, etc., in their respective territories, this very valuable information. If you have not already forwarded your order to the Washington Office, please do so immediately and remember that where orders for two hundred or more are placed we will imprint on the outside cover page, without additional charge, the name and address of the company.

American Society for Testing Materials Holds Annual Convention at French Lick Springs, Indiana

At the annual convention of the American Society for Testing Materials held June 20-24 technical papers and committee reports were heard on a wide range of structural materials. Of particular interest to crushed stone

producers was the report of Committee C-9 on Concrete and Concrete Aggregates which included an analysis of the tests made under the auspices of the committee to study the various theories for proportioning concrete.

The soundness of aggregates was also discussed in a special paper prepared by Mr. G. F. Loughlin, of the U. S. Geological Survey. Mr. Loughlin pointed out that certain types of stone containing the mineral bedellite was subject to failure upon exposure to the weather and should be given particular attention. The appearance of the old exposed ledge is the best criterion of possible failure in service. It was stated that the sodium sulphate test generally detected unsuitable stones. One case was cited, however, in which this did not seem to be the case.

A symposium on field control of the quality of concrete involving proportioning, mixing, conveying and placing, construction and expansion joints, insuring quality of concrete in cold weather, transverse tests as a criterion of the quality of concrete and the field testing of concrete were given discussion.

Associate Members of The National Crushed Stone Association

Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Crushing Plants and Machinery.

American Manganese Steel Co., Chicago Heights, Ill.
"Amsco" Manganese Steel Castings.

American Tar Products Co., Union Trust Bldg., Pittsburgh, Pa.
Tar Products for Road Construction and Maintenance.

Armstrong Manufacturing Co., Waterloo, Iowa.
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Atlas Powder Co., Wilmington, Del.
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Burrell Engineering & Construction Co., 513 West Jackson Blvd., Chicago, Ill.
Design and Construction.

Canadian Explosives, Limited, Canada Cement Bldg., Montreal, Can.
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The Carroll Chain Co., 265 Hosack St., Columbus, Ohio.
"Carroll" Solid Weld Steam Shovel Hoisting Chains.

Cement Mill and Quarry, 542 Monadnock Block, Chicago, Ill.
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The Columbus McKinnon Chain Co., 5th and Merrith Sts., Columbus, Ohio.
Hercules Solid Weld Steam Shovel Chain.

Cross Engineering Works, Carbondale, Pa.
Perforated Metals.

The R. & J. Dick Co., Passaic, N. J.
"Dickbelt," for Transmission, Elevating and Conveying.

E. I. du Pont de Nemours & Co., Wilmington, Del.
Explosives of All Kinds and Blasting Accessories.

Easton Car and Construction Co., Easton, Pa.
Quarry Cars.

Ensign-Bickford Co., Simsbury, Conn.
Safety Fuse and Cordeau Bickford Detonating Fuse.

Fairbanks, Morse & Co., 347 W. 4th St., Cincinnati, Ohio.
Diesel Engines, Electric Motors.

Fate-Root-Heath Co., Plymouth, Ohio.
"Plymouth" Gasoline Locomotives.

Flexible Steel Lacing Co., 4607 Lexington St., Chicago, Ill.
Alligator and Flexco H. D. Belt Fasteners.

Frog, Switch & Mfg. Co. Carlisle, Pa.
Manganese Steel Castings.

General Electric Co., Schenectady, N. Y.
Electrical Apparatus and Supplies.

Gill Rock Drill Co., Lebanon, Pa.
Blast Hole Drilling and Fishing Tools.

Good Roads Machinery Co., Kennet Square, Pa.
Crushers, Elevators, Elevator Feeders and Revolving Screens.

The Goodyear Tire and Rubber Co., Inc., Akron, Ohio.
Belting: Transmission, Conveyor, Elevator; Hose, Packing.

Grasselli Powder Co., Cleveland, Ohio.
Manufacturers of Explosives.

Harnishchfeger Corporation, 38th & National Aves., Milwaukee, Wis.
Gasoline, Electric and Diesel Shovels—Cranes and Draglines.

The Hayward Co., 50 Church St., New York City.
Hayward Orange Peel and Clam Shell Buckets.

The Hendrick Mfg. Co., Carbondale, Pa.
Perforated Metal Screens, Elevator Buckets.

Heisler Locomotive Works, Erie, Pennsylvania.
Geared Locomotives.

Hercules Powder Co., Wilmington, Del.
Explosives and Blasting Supplies.

C. W. Hunt Co., 1580 Richmond Terrace, West New Brighten, N. Y.
Mitchell Electric Vibrating Screen.

Ingersoll-Rand Company, 11 Broadway, New York City.
Rock Drills, Steel Sharpeners, Oil Furnaces and Hoists.

The Jeffrey Mfg. Co., Columbus, Ohio.
Elevating and Conveying Machinery.

Keystone Lubricating Co., Philadelphia, Pa.
Lubricating Greases and Lubricating Devices.

Keystone Division, McGraw-Hill Publishing Co., 10th Ave. at 36th St., New York City.
"Publishers."

Koehring Company, Milwaukee, Wis.
Gasoline Shovels, Cranes and Draglines.

Koppel Industrial Car and Equipment Co., Koppel, Pa.
Industrial and Portable Railway Material Work.

The Loomis Machine Co., Tiffin, Ohio.
Blast Hole, Prospecting and Drilling Machinery and Tools.

Manganese Steel Forge Co., Richmond St. and Erie Ave., Philadelphia, Pa.
"Rol-Man" Screens, Chains, Plates and Forged Products.

The Marion Steam Shovel Co., Marion, Ohio.
Power Shovels and Cranes—Steam, Gasoline and Electric.

Mid-West Locomotive Works, Cor. Spring Rd. and Alabama Ave., Cincinnati, Ohio.
Quarry Locomotives.

New York Belting & Packing Co., 91 Chambers St., New York City.
Conveyors, Elevator and Transmission Belting.

The Ohio Locomotive Crane Co., Bucyrus, Ohio.
"The Ohio Crane."

The Osgood Company, Marion, Ohio.
Power Shovels and Combinations.

Pit and Quarry, Rand McNally Bldg., Chicago, Ill.
"Publishers."

Rock Products, 542 So. Dearborn St., Chicago, Ill.
"Publishers."

Robins Conveying Belt Co., 15 Park Row, New York City.
Material Handling and Screening Equipment.

The Sanderson-Cyclone Drill Co., Orrville, Ohio.
Drills, Big Blast Hole, Drilling and Fishing Tools.

Sauerman Bros., Inc., 438 So. Clinton St., Chicago, Ill.
Cableway Excavators—Power Scrapers.

Shope Brick Co., East 8th and Division Sts., Portland, Oreg.
Concrete Brick.

The Orville Simpson Co., 1230 Knowlton St., Cincinnati, Ohio.
Screens, ROTEX, level, self-cleaning, 100 to ¼" mesh.

Smith Engineering Works, 32nd and Locust Sts., Milwaukee, Wis.
Rock Crushers—Gyratory, jaw and reduction.

Symons Bros. Co., 111 W. Washington St., Chicago, Ill.
Ore, Rock and Gravel Crushers.

S. G. Taylor Chain Co., 140 So. Dearborn St., Chicago, Ill.
Taylor Mesaba Steam Shovel Chains.

Taylor-Wharton Iron & Steel Co., High Bridge, N. J.
TISCO Manganese Steel Castings.

The Thew Shovel Co., Lorain, Ohio.
Steam, Gasoline and Electric Shovels, Cranes, Draglines.

The Traylor Engineering & Mfg. Co., Allentown, Pa.
Crushing, Cement and Mining Machinery.

Traylor Vibrator Co., 1400 Delgany St., Denver, Colorado.
Vibrating "Screen Supreme."

Trojan Powder Co., Allentown, Pa.
Explosives and Blasting Supplies.

Troco Lubricating Co., Philadelphia, Pa.
Manufacturers of Petroleum Products.

The W. S. Tyler Co., Cleveland, Ohio.
Woven Wire Screens and Screening Equipment.

Union Explosives Co., Clarksburg, W. Va.
Explosives and Blasting Supplies.

Vulcan Iron Works, Wilkes-Barre, Pa.
Steam, Gasoline, Electric Locomotives.

Western Wheeled Scraper Co., Aurora, Ill.
Western Portable Rock Crushers.

George D. Whitcomb Co., Rochelle, Ill.
Gasoline Locomotives.

Williams Patent Crusher and Pulverizer Co., 813 Montgomery St., St. Louis, Mo.
Hammer Crushers.